that no correlation exists between style-length and any other character, and as extensive intergradation is shown the two can scarcely be maintained as independent. The plant with especially compact habit, longest leaves 8 to 12 mm, corolla-tube 8 to 14 mm, and styles 3 to 6 mm in length is therefore here made a subspecies: *P. austromontana* **densa** (Brand) Wherry, status novus.

All three of these subspecies were first described from southwestern Utah; subsp. *vera* is now known to occur in all the Western States south of lat. 45°. Subsp. *prostrata* extends to southern California, where it is especially frequent, and to southeastern Arizona. Subsp. *densa* apparently occurs only from west-central Utah to middle Arizona.

ZOOLOGY.—*Observations on the distribution and ecology of the oribatid mites.*[1] WENDELL H. KRULL, U. S. Bureau of Animal Industry.

The oribatid mites have been incriminated only recently as intermediate hosts of economically important tapeworms of livestock. Stunkard (1937) reported recovering from experimentally infected mites, *Galumna* sp., cysticercoids of the common sheep tapeworm, *Moniezia expansa.* Later Stunkard (1939) reported in detail the experiments leading to this discovery and noted that "all the mites used fall within the generic concept of *Galumna.*" He did not, however, identify definitely the infected mites as to species. Stunkard's work has subsequently been confirmed by Stoll (1938) and by the writer (Krull, 1939). Stoll reported infecting two kinds of mites, *Galumna* sp. and *Galumna nigra* (Ewing), by feeding to these arthropods eggs of *Moniezia expansa,* while the writer recovered infective cysticercoids of this tapeworm from mites, *G. emarginata* (Banks), which had been collected on pastures. The cysticercoids collected by the writer were administered to a tapeworm-free lamb, and specimens of *M. expansa* were recovered from this host animal at necropsy.

Although extensive studies on the oribatid mites have been published by Michael (1884, 1898), Banks (1915), Ewing (1917), and Jacot (1937), very little is known of their distribution and ecology. In order to obtain information on these points, which is needed before control measures for the anoplocephaline tapeworms of livestock can be formulated, a preliminary investigation was undertaken to determine under what conditions these mites occur, and the influence of climatic and other factors on their distribution and abundance. The results of this investigation are given herein. Some preliminary observations on the food habits of these mites and attempts to culture them are also included.

[1] Received June 27, 1939.

METHOD OF COLLECTING ORIBATID MITES

Conventional methods of collecting free-living mites were of limited value because in this study mites were required in large numbers, and from grass collected under all weather conditions, therefore, the following method was devised: Grass from which oribatid mites were to be collected was cut with ordinary grass shears and transferred in buckets to the laboratory. The grass was then washed immediately by transferring it, not over one pound at a time, to a parallel-sided glass jar, having a capacity of about 14 liters. The jar was filled to within several inches of the top with tap water having a temperature of not more than 60° F. The grass was plunged up and down several times in the water, then removed, a small amount at a time, after it had been agitated again in the water to remove any mites that might have remained attached. When all the grass had been removed, the washings were poured into a similar container through a screen having 34 meshes to the linear inch. The jar in which the grass had been washed was rinsed with water of the same temperature at least once and the washings poured through the screen, care being taken to cover most of the screen surface in order to remove any remaining mites. While the contents of the jar settled, the surface was examined for mites and any that appeared there were removed. After 2 or 3 minutes the water, except for 1 to 2 liters, was very carefully and quickly decanted. The remaining portion with the sediment was agitated and transferred to a 4-liter battery jar. The larger jar was rinsed with enough cold water to fill completely the smaller jar to within about an inch of the top. During sedimentation the surface of the water was examined again for mites, and any that were present were removed. As soon as the solid contents had settled the water was carefully and quickly decanted, leaving in the jar about 150 cc, which, after being agitated, was transferred to a 250-cc cone-shaped graduate, filling it to near the top. After the contents had settled and any mites coming to the surface had been removed, about 200 cc of the water was very carefully decanted and replaced by water having a temperature of 113° F. The addition of warm water changed the density of the medium and forced the mites to the surface and through the film formed by the surface tension so that they could be removed. For this procedure two teasing needles were held crossed and close together near the mites. When the needles were raised slowly the mite or mites adhered to one of the two needles. By touching the needle with the mite to a drop of water in the center of a watchglass the mite was released and would slide down the film formed by the surface tension to the edge of the drop, where it became imprisoned. When all the mites had been transferred to the drop and while under observation through a binocular microscope they were drawn to one side and out of the drop with a teasing needle. The drop of water was then removed with a pipette. As soon as the water around the mites dried, one part of a gelatin capsule was slipped over them and while this was held in place the dish was inverted to transfer the mites; the remaining part of the capsule was then replaced. The mites were retained in the closed capsule until needed.

Though this method may appear somewhat unwieldy and unpractical, it will be found after a little practice to be quite efficient. However, certain details must be observed in order to obtain satisfactory results. In collecting the grass care must be taken to prevent loss of mites through undue disturbance, especially when the grass is dry. It is best to carry the washing process to its completion in the least possible time to prevent loss of mites. When the washings are sedimenting in the larger jar immediately after being screened, it is only rarely that a mite will be found on the surface. However, while the material is in the smaller jar a few of the mites may come to the surface, and these should be removed immediately. The number of mites coming to the surface in the smaller jar is usually an index to the final count, since 3 to 5 percent of the mites for each pound of grass seem to appear on the surface at this time. A few mites may be found on the surface of the cold water in the small graduate, but the limited surface makes it easy to remove them quickly. When the water at higher temperature is added, the majority of mites come to the surface; this has been verified by examination of the debris. To make sure that the mites were not imprisoned in the debris, the contents of the cone were agitated several times with a steel knitting needle.

Oribatid mites on the surface of the water are very distinctive in appearance and resemble tiny black or brown glistening pearls. It is only rarely that enough debris, including various organisms, comes to the surface to interfere seriously with the removal of the mites; should this happen, jarring the container or agitating the surface slightly with a needle will cause the debris to sink.

The heat of the water does not destroy the mites, although sometimes it seems to reduce their vitality. If it is desired to keep the mites alive for some time, the hot water should be omitted, leaving the cold water in the graduate. As the water temperature increases, the mites rise slowly and continue to rise for periods up to 3 hours.

Any attempt to shorten the process by omitting the second or battery-jar stage of washing, which involves decanting enough water from the large container to transfer the remaining contents directly to the small graduate, will lead to unsatisfactory results.

In order to obtain the maximum number of mites from grass from a given area, the samples should be collected in the morning following a rain sufficient to saturate the ground. The grass at the time collected should be only slightly moist, the day cloudy, and the collection made as soon after daylight as possible. When the number of mites per pound of grass is large, it is well to wash the grass a second time in order to obtain the maximum number present.

OBSERVATIONS ON THE ECOLOGY OF ORIBATID MITES

The data so far obtained are based on the study of mites from October 18, 1937, to May 27, 1938. The conclusions relative to abundance, distribution, and conditions affecting the mites were reached from a study of the mites collected from 359 samples representing a total of 618 pounds of grass. The samples varied in weight from 1 ounce to 3 pounds, with an occasional larger sample; these samples were collected from 12 stations at the Agricultural Research Center, Beltsville, Md. A total of 18,238 oribatid mites were recovered from the grass collected and examined; this represented an average of about 30 mites per pound of grass.

The following species of mites[2] were collected: *Dameosoma minuta* Ewing, *Galumna curva* (Ewing), *G. emarginata* (Banks), *G. minuta* (Ewing), *G. rugosala* (Ewing), *Notaspis spinipes* (Banks), *Oribatula minuta* (Ewing), *Oripoda elongata* Banks and Perg., *Phthiracarus americanus* Ewing, *Zygaribatula clavata* (Ewing), unidentified species of *Ceratozetes*, *Fuscozetes*, *Galumna*, *Liebstadia*, *Neoribates*, *Oribatella*, *Pelops*, *Scheloribates*, *Sphaerobates*, and *Zygaribatula*, and new species in at least two new genera. The species collected from an old, permanent, open sheep pasture were *Galumna emarginata* (Banks), *G. minuta* Ewing, *Galumna* sp., *Oribatula minuta* (Ewing), *Oribatula* sp., *Pelops* sp., *Scheloribates* sp., and *Sphaerobates* sp.

Factors affecting distribution of oribatid mites.—The mites in the area studied were rather general in distribution, and an occasional one could be found almost anywhere, even in areas that were quite barren. In certain grassy areas, however, which, judged from all known data concerning their habitat, should have had mites in

[2] The identifications were made by Dr. H. E. Ewing, of the U. S. Bureau of Entomology and Plant Quarantine.

abundance, these arthropods were found only with difficulty. The mites were more apt to be found in abundance and retained the greatest constancy in areas where moisture was plentiful enough to prevent limitation of the growth of grass.

The mites were found in considerable numbers under almost any pasture condition. In open pastures having only occasional deciduous trees, the shaded areas did not influence to any extent the distribution of the mites, except that during the winter months a few more mites were always collected from around the isolated trees. The mites were much more apt to be abundant in pastures shaded by coniferous trees, where the organisms were protected throughout the year from the effects of sudden and excessive changes of environmental conditions. In the area studied the mites were most abundant in a heavily shaded flat pasture surrounded by coniferous and deciduous trees and containing grass of a soft texture and about 6 inches high. The mites were not reduced excessively by prolonged cold wet weather of a week's duration or by a prolonged dry spell of a month, if these changes occurred during spring and early summer.

The relative number of mites found on the grass in a given location varied tremendously with conditions of environment, the influence of some factors having been ascertained. Those factors that have been more or less definitely established as influencing the vertical distribution of the mites are water, light, wind, and food.

The mites seem to have a very delicate adjustment to water, and succumb readily at room temperature if they are not protected from evaporation; they may be floated on water, without taking food, for at least 18 hours. In their native habitat the mites apparently maintain their relationship to proper moisture conditions by their movements in and on the ground and on the grass, and in this respect they have considerable latitude with regard to moisture, as well as to other conditions. The proportion of mites on the grass in a given area apparently depends to a large extent on moisture conditions. They were the most abundant the day after a heavy rain sufficient to saturate the ground thoroughly, and this was found to be the only time that an estimate could be obtained from grass samples of the number of mites in any location. Since the mites respond negatively to excessive moisture, it may be assumed that their presence in large numbers in the grass after heavy rains is an attempt on the part of the mite to escape this moisture. In accordance with this response it has been found that light rains, heavy fogs, and dew do not change materially the distribution of the mites, and of these conditions the light rains affect them most. Their response to snow was not studied, but it was possible always to collect them from grass covered with snow.

The mites avoid excessive light, and on clear days very few if any could be collected from grass; they were most abundant immediately after daybreak. On cloudy days they remained somewhat more numerous and constant throughout the day. They appear to leave the grass when there is a high wind. The number of mites on the grass increased immediately when a cloudy day with light rains succeeded a period of 2 or 3 days without rain.

Just what effect temperature has on the mites has not been definitely determined, but from the observations made it seems to have little or no effect. As previously mentioned, mites were collected from grass cut in snow; moreover, they were as abundant on grass at a temperature of 20° F., the lowest encountered during the period covered, as they were at higher temperatures.

Seasonal distribution.—The mites were found to be much more abundant in spring than in winter, and there is a very sudden and striking increase in numbers when the new spring growth of grass is about 3 inches tall. It is possible that a part of this increase in mites is the result of the accumulation of eggs and young during the winter months, when periods of warm weather are not of sufficient duration to allow the mites to mature but are long enough for the adults to feed and lay eggs. The relative number of mites present during fall and winter as compared with the number present in spring after the new growth of grass appears may be deduced roughly from the following data: From 406 pounds of grass collected from October 18 to March 17, a total of 4,898 mites were obtained, whereas 13,340 mites were recovered from 212 pounds collected from March 18 to May 27. From 226 pounds of grass collected in a sheep pasture from October 18 to March 17, 1,821 mites were recovered as compared with 59 pounds of grass collected in the same pasture from March 18 to May 27, which yielded 4,527 mites.

Prevalence of mites on grass.—On the basis of the data so far obtained, it appears that the actual number of mites on grass varies considerably, and that there are times, even in spring, when no mites can be recovered. The largest number of mites per pound of grass recovered from an open sheep pasture was 619; these were obtained from 15 ounces of grass taken on May 20. The largest number prior to the time of the spring growth of grass was 100 per pound, which were obtained from a $2\frac{1}{2}$-pound sample collected on February 18.

The largest number per pound of grass was from samples taken from a shaded pasture, where 2,547 mites were obtained from 2 pounds of grass collected at 9 a. m. on May 19. From this same pasture 1,158 were taken from 1 pound 10 ounces of grass at 11 a. m. on March 31. Because of excessive grazing, not enough collections were made prior to the time that the spring growth appeared to give a comparison. In an area frequented by wild rabbits, on the edge of a pond, the largest number of mites per pound of grass was 325 from a 1 pound 4 ounce sample collected at 9 a. m. on March 18; the largest number prior to the spring growth of grass was 187 from 1 pound 4 ounces of grass taken on October 29.

Under ordinary dry conditions, beginning on the fourth day after a rain, it was unusual to find the mites in greater abundance than 5 per pound of grass after 9 a. m. The variation in the numbers of mites present in a given area on different, yet not widely separated, days is shown by the following data: From a collection of 1 pound 13 ounces of grass taken at 8 a. m. on May 16, 168 mites were obtained. In the same area a collection of 1 pound 4 ounces of grass taken at 9 a. m. on March 28 yielded 12 mites, whereas 1 pound 10 ounces of grass collected at 11 a. m. on March 31 yielded 1,158 mites.

Response to artificial change of conditions.—After the abundance and distribution of the mites in a pasture had been ascertained, certain selected portions were fenced. These areas were used for the purpose of encouraging the multiplication and growth of the mites. Pellets from two sheep contaminated with eggs of *Moniezia expansa* were spread on the areas during fall and winter months. This ground was never without water for more than 3 days; in the event that rain did not fall in the allotted time the ground was sprinkled. In the spring the excess debris was raked off and the areas were kept free from weeds. Grass samples from which the mites were collected were taken throughout the period of investigation, and during that time a few mites, rarely in excess of the general average, could always be collected. The record number per pound of grass, 115 mites, was taken from a 1 pound 10 ounce sample collected on April 15. The interesting fact about these areas was that the mites did not respond to this kind of treatment, as indicated by the small number collected from the grass samples. The reason for this indifferent response is not apparent.

After it had been determined that the maximum number of mites on grass could be collected after rains extensive enough to saturate the ground, it was assumed that the same results could be obtained by sprinkling areas and cutting the grass the following day. However, the results were not as anticipated. Usually the sprinkling increased slightly the number of mites on the grass, the maximum results achieved comparing favorably with those following light rains.

Relative abundance of species.—Beginning in March mites were separated into several distinguishable types, some of which represented distinct species; consequently, comparisons as to abundance and distribution can be given. The total number of mites collected and separated from all localities studied was 11,310, and of these 568 were *Galumna emarginata*, which had been determined by the writer (Krull, 1939) to be an intermediate host of the sheep tapeworm, *Moniezia expansa*.[3] The mite was found to be generally distributed, having been collected at all seasons studied; however, it was more variable as to relative numbers when compared to the rest of the mites. These mites were most abundant during April and May, and at this time more abundant in an open pasture than in one that was heavily shaded. In an open pasture in which there was a single deciduous tree, the mites were most numerous during fall and winter in the grass around the tree than in the rest of the pasture; in spring the conditions were reversed. During the winter months this mite was found to be commonest on an area near a pond where moisture conditions were the most constant of any area studied. In spring the mites were the most numerous in an open, low-lying, flat, undergrazed pasture in which the grass was rather high. *Galumna emarginata* was rarely more abundant than 5 per pound of grass at any time or in any plot, although in one exceptional case 89 were taken from 15 ounces of grass collected on May 20 from the low-lying pasture.

Galumna minuta was the commonest mite found, and of the 11,310 mites already mentioned 7,270 were of this species. This species was generally distributed and was collected from all stations in all seasons studied.

Nymphs of oribatid mites could be found at all seasons but were commonest during the last week in March and during the last week in May.

[3] During April and May, 286 specimens of *Galumna emarginata* collected from pastures contaminated with eggs of *M. expansa* were dissected and examined for larval tapeworms. Five were found to be infested, each containing one fully developed cysticercoid; one of the mites had, in addition, two undeveloped cysticercoids that had attained nearly maximum size. One other mite collected in November contained a fully developed larva. Four of the 5 cysticercoids were measured without pressure in water and averaged 178μ long by 147μ wide, the largest being 200μ by 150μ and the smallest 160μ by 145μ. During the same months 2,606 specimens of *G. minuta* were examined for cysticercoids and all were negative. Of the other species of oribatid mites, 623 were examined and all were negative.

OBSERVATIONS ON THE FOOD HABITS OF ORIBATID MITES

The oribatid mites in general eat hyphae and spores of fungi, debris, anoplocephaline tapeworm eggs, and cellular material of blades of dead grass in certain stages of decomposition. They exhibit considerable choice as to the fungi they eat, devouring only certain of the white fungi and their black spores, ignoring completely any in which the hyphae are colored. The fungi are eaten in a moist or dry state. The mites have gluttonous appetites and devour an enormous amount of material. In feeding them eggs of the tapeworm *M. expansa*, it was found the debris surrounding the eggs as well as the eggs was desired as food. Eggs that were moist were not accessible to the mites and were merely pushed around by them. Eggs that were accessible had to be well anchored and apparently dry. Since the mouth parts of the mites are such as to prevent the ingestion of the egg in its entirety, the mites gain entrance to the eggs by making a hole in the outer dry membranes and ingest the contents which are freed in this manner. The remaining parts of the membranes are usually ignored. Mites have been observed to work for considerable periods of time before succeeding in making an opening in an egg. The observations concerning the reactions of the mites to tapeworm eggs may be easily demonstrated by applying eggs to pieces of agar dispersions which are dried and placed in a container where the mites have access to them.

CULTURING ORIBATID MITES

Attempts were made to culture the various oribatid mites in covered stender dishes of several sizes and in various larger containers. For substratum substances soil, sand, paper, filter paper, and agar dispersions have been used, and pebbles, grass leaves, decaying plant material, and pieces of agar and paper have been employed to give them retreats and cover. Fungi in addition to those transferred accidentally to the habitat were supplied on pieces of grass leaves and pieces of agar. Numerous mites have been raised in this way, but no method has been found that could be depended on to give consistent results. The number of nymphs sometimes appearing in an experimental habitat was exceedingly large in view of the number of adults supplied for stock and the small number of eggs carried by the mites at one time.

The individual species varied considerably in their response to artificial culture. Species of the genus *Galumna* were the most difficult to handle. *G. minuta* was raised to maturity in several cultures. *G. emarginata* although the largest and most robust mite encountered was the most difficult to handle and could be kept at most only a couple of weeks. Nymphs of *G. emarginata* hatched under artificial conditions lived only a few days.

SUMMARY

A method for collecting oribatid mites under all weather conditions has been described.

Oribatid mites in the region studied were most abundant on grass after rains sufficient to saturate the ground, and they retained their greatest constancy in areas where moisture was plentiful enough to prevent limitation of the growth of grass. Numerous mites of the various species recorded could be collected from sheep pastures. Water, light, wind, and food are factors that were found to be important in influencing the vertical distribution of the mites on grass. A striking increase in the number of mites on grass was observed at the time the spring growth of grass was 3 inches tall. Mites kept under controlled conditions ate hyphae and spores of fungi, debris, cellular material of blades of dead grass, and anoplocephaline tapeworm eggs.

Numerous mites of the various species recorded were dissected and examined for cysticercoids of *Moniezia expansa*, which were found only in *Galumna emarginata*. This mite was generally distributed, could be collected at all seasons during which the investigation was in progress, and was taken only rarely in greater numbers than 5 per pound of grass.

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